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A Simple Evapotranspiration Model for Hawaii: The Hargreaves Model

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Information on evapotranspiration (ET), or consumptive water use, is significant for water resources planning and irrigation scheduling.

Potential evapotranspiration (PET, or ET_0), which is the consumptive water use of a field situation where the soil is not under moisture stress, can be estimated using pan evaporation from a free water surface. Where pan evaporation data is not available, ET can be calculated by ET models using climatological parameters. Among them, the Penman model is most frequently used for ET estimation. The Penman model requires five climatic parameters: temperature, relative humidity, wind, saturation vapor pressure, and net radiation. It also uses complicated unit conversions and lengthy calculations. The Hargreaves model is a simpler model that requires only two climatic parameters, temperature and incident radiation.

Most ET models were developed based on data of durations such as 7, 10, or 30 days. When these models are used for estimating daily ET for irrigation scheduling, there will be a discrepancy between the actual daily consumptive use and the calculated ET value. This discrepancy will not be significant as long as the total amount for a longer duration can be matched. The soil in the root zone can adjust itself to store and release soil water as required in the field. Any soil that has a water-holding capacity of more than one inch in the range of soil moisture required for good plant growth can handle a 7- or 10-day fluctuation when an amount of water equivalent to the daily ET is applied for irrigation.

Six ET models were applied to determine daily ET based on climatic data collected for three years by an automatic weather station at the CTAHR Waimanalo Research Station. The effectiveness of the models was evaluated by comparing daily evaporation readings with the daily ET determined with the climatic data collected.

A moving average of daily readings of evaporation and calculated ET from six ET models (Penman, Revised Penman, Jensen-Haise, Hargreaves, Kohler, and Taylor) were used to evaluate the effectiveness of the ET model. The results showed that the correlation between daily readings was not as good as expected; however, excellent correlations were found for all ET models, except the Kohler model, when a 7-day or longer moving average of daily readings was used. The regression coefficient (R^2) was only about 0.64 for daily readings but increased to nearly 0.90 when the 7-day moving average was used. A 15-day moving average analysis increased the R^2 to 0.94. The correlation results indicated that for fields in Hawaii the simple Hargreaves model can be used to estimate ET as accurately as the complicated Penman model.

The Hargreaves model

Among the ET models evaluated, the Hargreaves model is the simplest one for practical use, since it requires only two easily accessible parameters, temperature and solar energy. The Hargreaves model is expressed as follows:

$$ET_0 = 0.0135\,(T + 17.78)\,R_S \qquad (1)$$

where ET = potential daily evapotranspiration, mm/day; T = mean temperature, °C; and R_S = incident solar radiation converted to depth of water, mm/day.

There are two common units for solar radiation: megajoule per square meter (MJ/m^2) and the Langley. One Langley is equivalent to one calorie per square centimeter. When the solar energy is expressed as Langleys, Equation 1 will be expressed as

$$ET_0 = 0.0135\,(T + 17.78)\,R_S \left(\frac{10}{595.5 - 0.55T}\right) \qquad (2)$$

where R_S becomes the incident solar radiation expressed as Langleys/day.

When the solar energy is expressed as megajoules per square meter, Equation 1 will be expressed as

$$ET_0 = 0.0135\,(T + 17.78)\,R_S \left(\frac{238.8}{595.5 - 0.55T}\right) \qquad (3)$$

where R_S becomes the incident solar radiation expressed as MJ/m^2/day.

ET determination and irrigation scheduling

The Hargreaves model shown in Equations 2 and 3 can be used to calculate consumptive use for agricultural fields in Hawaii, which is the potential evapotranspiration (ET_0) for a field under no soil moisture stress ("field capacity"). The daily ET_0 can be determined by only two common climatological parameters, temperature and solar energy, which are easily obtained by simple instruments and are available for many locations. Equations 2 and 3 are used for the incident radiation units expressed as Langleys and MJ/m^2, respectively.

Irrigation applications can be made daily with an amount determined by the calculated daily ET_0. An initial soil moisture situation can be set as close as possible to field capacity in the root zone by applying a pre-wetting irrigation of 25–50 mm (1–2 inches) to the field. Irrigation schedules, according to ET, will be started 3–5 days after the pre-wetting; this will make room for soil moisture adjustments to compensate the discrepancies between the actual daily ET and the ET_0 calculated by the Hargreaves model.

Two design charts were developed based on the Hargreaves model given in Equations 2 and 3. The daily ET_0 can be read from the charts by using the daily mean temperature and incident radiation. Figure 1 is used for incident radiation expressed in Langleys/day, and Figure 2 is used for incident radiation expressed in MJ/m^2/day. Two design examples are presented, as follows:

Example 1. When the mean daily temperature is 20°C and the total solar energy is 500 Langleys/day, determine the daily ET.

1A: calculating with Equation 2,

$$ET_0 = 0.0135\ (20 + 17.78)\ 500 \left(\frac{10}{595.5 - 0.55 \times 20}\right)$$
$$= 4.37 \text{ mm/day}$$

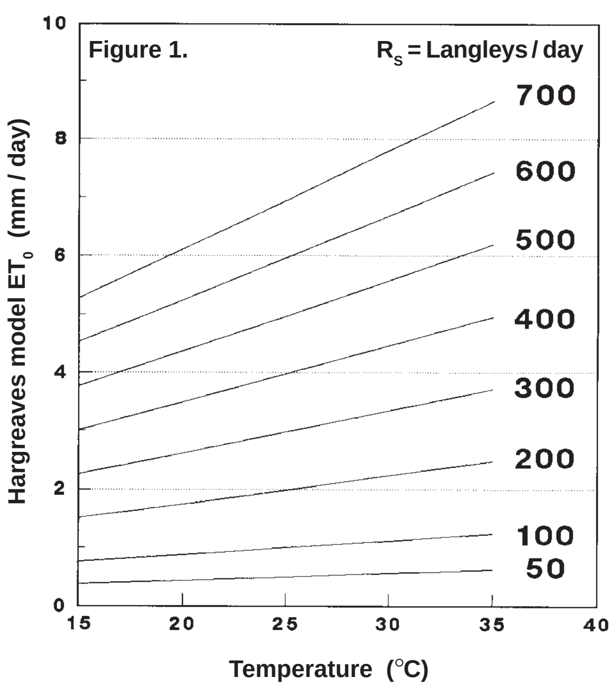
1B: using Figure 1, when T = 20°C and R_S = 500 Langleys/day, the ET_0 can be read directly as 4.4 mm/day.

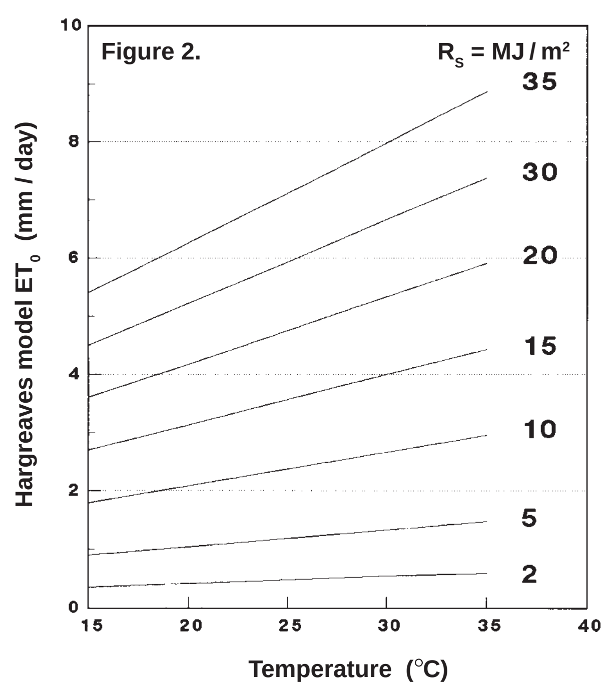
Example 2. When the mean daily temperature is 25°C and the total solar radiation is 20 MJ/m^2/day, determine the daily ET.

2A: calculating with Equation 3,

$$ET_0 = 0.0135\ (25 + 17.78)\ 20 \left(\frac{238.8}{595.5 - 0.55 \times 25}\right)$$
$$= 4.74 \text{ mm}$$

2B: using Figure 2, when T = 25°C and R_S = 20 MJ/m^2/day, the ET can be read directly as 4.7 mm/day.





Acknowledgments

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